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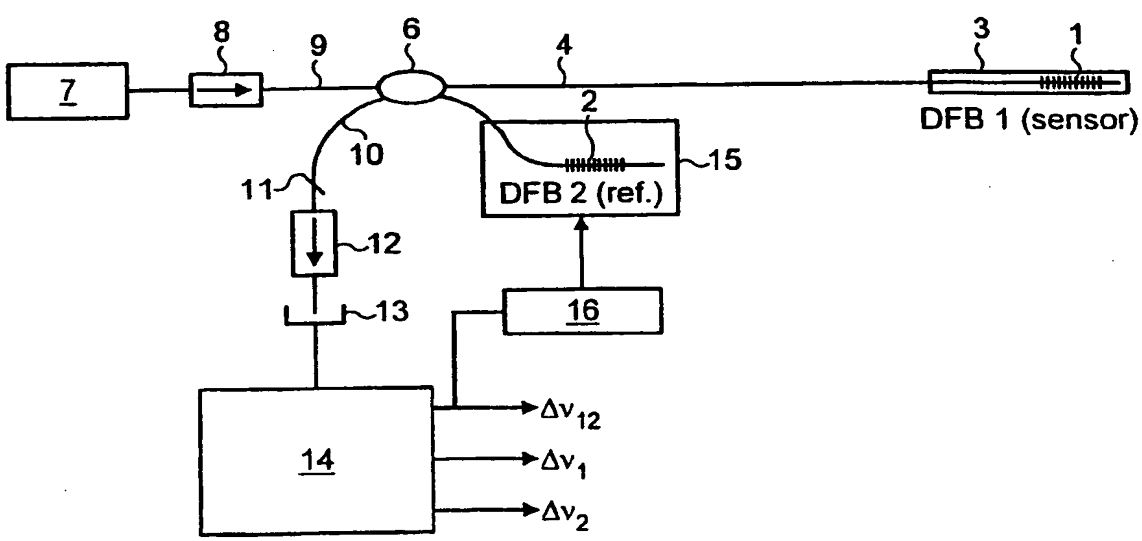

(57) Abstract: A fibre optic sensor system comprises at least one measuring sensor 1 providing an optical output dependent upon one or more parameters to be measured, e.g. temperature, and at least one reference sensor 2 providing a reference output for comparison with the measuring sensor output. The reference sensor is provided in a birefringent fibre. The system includes a detecting means 13,14 whereby a reference beat signal f_2 is derived by measuring the optical frequency splitting between frequency components in different polarisation planes of the reference sensor output. A further beat signal f¿3 ?is generated between the measuring and reference sensor outputs, such beat signals being used to derive a measurement of one or more parameters.

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Fibre Optic Sensor Systems

This invention relates to fibre optic sensor systems, and relates in particular to improvements in such systems enabling more accurate and higher resolution measurements of optical signals derived from fibre optic sensors.

There are a variety of fibre optic sensors, such as Bragg grating sensors, fibre laser sensors, and interferometric sensors having the potential for measuring small changes in temperature, pressure or strain on or established in an optical fibre. Strains can be induced by physical, chemical or biological parameters, or by electromagnetic fields, and these sensors can be configured to measure accurately a variety of different parameters (measurands). Hence, it is known that optical fibres may be provided with claddings or coatings which react to particular measurands to establish strain within a fibre, this strain changing a detectable optical property of the fibre such that a particular parameter can be measured.

Such sensors are used in medical applications, and in various other applications including engineering and oil and gas exploration.

In relation to such sensors, the varying optical properties of the fibre at one or more sensing locations thereof can be provided by various known means. For example, sensing regions of the fibre may be configured to provide a form of "Fabry-Perot" (F-P) interferometer, whose resonance wavelength when interrogated by a suitable laser light source depends on strain established within the fibre. In such a system there are effectively spaced "mirrors" written into the fibre whose spacing determines the output wavelength which therefore changes with longitudinal strain within the fibre.

Alternatively, the sensing regions can be based on active or passive fibre Bragg gratings (FBG's) written into the optical fibre core. These gratings are made by producing periodic variations in the refractive index along a short section or sections of the core, and methods for fabricating such gratings are generally known in the art.

Passive FBG devices, and interrogating systems therefor, are known, for example, from US 5,828,059 and US 6,097,487.

As described in US 5,828,059, for example, standard FBG devices, each operating with a different nominal operating frequency, may be advantageously written into a birefringent optical fibre, such as a side-hole fibre, which provides spectral peaks in its optical response which are spaced apart in mutually orthogonal polarisation axes of the fibre. Strain established in the fibre, which may be temperature dependent, changes the birefringence, and causes a measurable change in the wavelength spacing between the spectral peaks of the reflected light in mutually orthogonal polarisation planes.

An interrogating system suitable for measuring the positions of spectral peaks or notches derived from FBG sensors having different operating wavelengths relative to a reference wavelength is described in US 6,097,487. In this system, part of the interrogating broad band light source is transmitted through or reflected from a Fabry-Perot interferometer configured to create a comb spectrum. Such a comb spectrum can provide an accurate frequency or wavelength scale for comparison with the respective spectral peaks or notches from sensors operating at different wavelengths, such that the through the use of suitable signal processing means accurate and repeatable wavelength measurements can be obtained. In US 6,097,487 the reference grating and the sensor gratings are not provided in birefringent fibres,

and are configured to operate at different nominal wavelengths.

An alternative configuration of sensor involves the use of active fibre lasers, particularly active FBG lasers. Such devices, and interrogating systems therefor, are described in, for example, US 5,844,927 and US 5,564,832. In each of these systems, an end-pumped fibre laser with distributed feedback (DFB) oscillates on two orthogonally polarised wavelengths. The distance between these wavelengths is dependent upon birefringence of a fibre, and is therefore responsive to mechanical strain within the fibre. Such strain can be temperature or pressure dependent, or can be responsive to a variety of different measurands through the use of reactive coatings or claddings on the fibre, for example.

US 5,564,832 and 5,844,927 each describe interrogation systems in which the measurement of birefringence in a fibre laser sensor involves the measurement of electrical beat frequencies established between the different optical frequencies in the mutually orthogonal polarisation planes. As is well known, by superposing two slightly different frequencies together, a lower beat frequency is generated dependent upon the difference between the first two frequencies. The lower frequency regime of the beat frequency enables more convenient measurement of an electrical signal by known processing means.

In US 5,844,927, one or more sensor FBG's are written into birefringent fibres, such that a beat frequency indicative of the wavelength spacing in different polarisation planes for each FBG may be derived. These may be compared with the output signal from a reference FBG laser, which is not written into a birefringent fibre.

The use of a suitably calibrated reference FBG laser is intended to enable accurate measurement of

variations in the output from the sensor FBG's, which may be subjected to changes in pressure or temperature, for example.

In US 5,564,832, there are a plurality of birefringent FBG devices spaced along the length of a single optical fibre, which are configured to operate at different nominal wavelengths such that the outputs are multiplexed along a single fibre. The output from these lasers is optically demultiplexed using a diffraction grating device, such that optical signals of differing wavelengths from the respective lasers are separated before they are measured. In relation to each of the separated signals, beat frequencies are then generated which are dependent upon the wavelength spacing between the spectral peaks in different polarisation planes in relation to each sensor.

It is an object of the present invention to provide an improved fibre optic sensing system, which enables higher resolution and more accurate measurements of optical frequencies, and hence of selected measurands, compared with prior art devices.

Viewed from a first aspect the invention provides a fibre optic sensor system, comprising at least one measuring sensor providing an optical output dependent upon one or more parameters to be measured, and at least one reference sensor providing a reference output for comparison with the measuring sensor output, wherein the reference sensor is provided in a birefringent fibre, and the system includes a detecting means whereby a reference beat signal is derived by measuring the optical frequency splitting between frequency components in different polarisation planes of the reference sensor output, a further beat signal being generated between the reference measuring and reference sensor outputs, such beat signals being used to derive a measurement of one or more parameters.

A further aspect of the invention provides a fibre

optic sensor system including measuring and reference sensors written into respective optical fibres, in which at least the reference sensor is written into a birefringent fibre, and the system further includes a detecting means which operates by generating a beat frequency derived from the output of the reference sensor.

A still further aspect of the invention provides a method of sensing using fibre optic sensors, in which the output from a reference sensor provided in a birefringent fibre is used to derive a beat signal for comparison with the output from a measuring sensor provided in a second fibre.

A preferred mode of operation of such a system and method is that a beat frequency derived from the reference sensor output and a beat frequency derived from a comparison between the measuring sensor output and the reference sensor output are used to derive an indication of at least one parameter of interest without the need directly to measure the absolute frequency of either sensor by optical means.

The beat frequency in a birefringent fibre is proportional to the absolute frequency, and the system can be suitably calibrated such that the beat frequency derived from the reference sensor output provides an output indicative of reference sensor temperature, for example.

The beat frequency derived from the comparison between the reference and measuring sensors may then be added to or otherwise compared with this output to derive a further output which is indicative of measuring sensor temperature.

In other words, in such a system, there may be two unknown parameters, for example the measuring and reference sensor temperatures, and two beat signals, namely the reference sensor beat and the beat between the sensor outputs, which can be used to derive a

measurement of each unknown parameter without the need directly to measure the absolute frequency of either output by optical means.

In a preferred embodiment, the measuring sensor is also provided in a birefringent fibre such that the beat derived from this sensor can be used to measure a different parameter, such as pressure. Hence, in this embodiment, there would be three unknown variables, for example measuring sensor pressure and temperature and reference sensor temperature, and three beat frequencies from which measurements of each of these may be derived, again without the need directly to measure the absolute frequency of each sensor output by optical means.

Such systems can enable high resolution and accurate measurement of a frequency component of the measuring sensor output relative to the reference sensor output which is based on the frequency splitting between mutually orthogonal polarisation planes of a birefringent reference sensor fibre. This splitting will only depend on temperature provided that the reference fibre sensor is kept free from mechanical strain, and since there is one-to-one correspondence between absolute resonance frequency and the frequency splitting with varying temperature, the measured splitting is effectively a measure of the absolute reference frequency. The correspondence between splitting and absolute frequency, which is approximately linear, can be calibrated without difficulty.

The use of a birefringent reference sensor in this way can provide a more convenient and accurate reference measurement than is obtained, for example, in US 5,844,927 and in US 6,097,487, in which reference sensors are not written in birefringent fibres, and the reference signal provides only a single spectral peak or notch whose frequency must be measured for comparison with the measuring sensor spectra.

Moreover, the system of these aspects of the

present invention differ from those described in US 5,828,059 and US 5,564,832, in that the system includes at least one associated pair of measuring and reference sensors provided in different fibres and, in some embodiments, having substantially the same or similar nominal operating wavelengths so that a beat signal is generated between the reference and measuring sensor outputs. The systems may include a number of measuring sensors at different nominal wavelengths and multiplexed along a common respective fibre with a single reference sensor provided in a different fibre or with multiple reference sensors.

As discussed, in one aspect of the invention, the measuring and reference sensors of each pair have the same nominal operating wavelength. This can provide the more accurate and convenient comparison between the reference and measuring spectra. Further, there is no need for optical demultiplexing of the signals from each pair of associated reference and measuring sensors, and demultiplexing can instead be achieved in the electrical domain by processing electronics. This has practical advantages.

The birefringent fibre in which the reference sensor is provided may, for example, be a side-hole fibre, a D-fibre, a Bow-Tie fibre, a Panda fibre, or another fibre with special geometry which establishes a detectable change in birefringence in response to strain and temperature.

The reference scheme of the invention has a number of different applications. It can be used to provide accurate single parameter measurements in relation to pressure, temperature or chemical or biochemical measurands, depending on the configuration of the fibre optic sensor. In this case, the reference sensor can be used for temperature compensation, for example. The frequency splitting in relation to the optical output from the birefringent reference sensor can be accurately

measured to provide an indication of temperature of the reference sensor. This output can be compared with a frequency component of the measuring sensor, such comparison being particularly facilitated if the reference sensor has the same nominal operating wavelength as the measuring sensor. Based on this comparison the system can either derive a measurement of temperature at the measuring sensor, or can use the temperature measurement derived from the reference sensor to correct the output of the measuring sensor for variations in temperature, such that some other parameter can be derived from the measuring sensor, such as pressure.

The reference sensor should be kept free from strain and avoid large and fast temperature fluctuations.

The reference sensor may be located in an oven whose temperature is controlled in such a way that the reference sensor has the same nominal operating wavelength as the measuring sensor.

In an alternative arrangement, the reference sensor can be placed close to the measuring sensor. In this case, the reference sensor will naturally be at the same temperature as the measuring sensor, and the output therefrom can be used to correct the output of the measuring sensor for changes in temperature.

As is described in the prior art references discussed above, the measuring sensor can be configured in a known manner to be responsive to a variety of different measurands, in such a way that the measurands establish strain within the optical fibre in the region of the sensor in order to vary the optical response.

The or each measuring sensor may also be provided in a birefringent fibre. If the measuring sensor is not provided in a birefringent fibre, then, as discussed above, the detecting system will generally analyse only a single frequency component, i.e. a spectral peak or

notch, derived from the or each measuring sensor, and compare this with a signal based on the birefringent output of the reference sensor e.g. to generate a beat signal between the measuring and reference sensor outputs in the manner described above. Two independent single frequency sensors may be used, with the system analysing the difference in wavelength between the sensors.

In the presently preferred embodiments, the or each measuring sensor is also provided in a birefringent fibre, and provides a birefringent response in relation to which measurement can be based on the absolute frequency of the response, and/or on the spacing of spectral peaks or notches in mutually orthogonal polarisation planes. This spacing can be compared with the birefringent wavelength spacing derived from the reference sensor, such that the reference sensor can be used to calibrate or correct the output from the measuring sensor. Additionally or alternatively, the absolute frequency of the measuring sensor output can be used for measurements. This enables highly accurate dual parameter measurements to be made, where two parameters, such as pressure, temperature, or biochemical parameters, can be determined by measuring the absolute frequency of the measuring sensor, the absolute frequency of the reference sensor, together with the birefringent frequency splitting of each of these sensors. As discussed above, the absolute frequency of the measuring sensor may itself be derived from beats generated between the measuring and reference sensor outputs.

In one set of embodiments the reference and measuring sensors are in the form of active fibre lasers, preferably fibre DFB lasers. At least the reference laser, and preferably also the measuring laser, is/are written into a birefringent fibre, such that the outputs each consist of spaced spectral peaks

in different polarisation planes.

As discussed above, the system preferably includes detecting means which operates by generating beat frequencies in the electrical domain, which beat frequencies are lower than the optical frequencies and more convenient to measure. This general approach is known, for example, from US 5,844,927 and US 5,564,832.

Since the measuring and reference sensor lasers are, in accordance with this aspect of the invention, configured to have the same nominal operating wavelength, beat frequencies can be generated between the spectral peaks in the different birefringent axes of each laser, and also can be generated between frequency components of the respective lasers. Hence, three beat frequencies may, for example, be generated, a first dependent on the birefringence of the reference laser, a second dependent on the birefringence of the measuring laser, and a third dependent upon the difference between the lasing frequencies of the respective lasers, which beat frequencies may be indicative of particular parameters such as pressure and/or temperature in the environment of the measuring sensor. Alternatively, the measuring sensor may not be provided in a birefringent fibre, in which case beat frequencies may be based on the birefringence of the reference laser, and on the difference between the frequency of the measuring and reference lasers, which difference is established by strain in the measuring laser responsive to a particular measurand.

In either case, the output from the reference laser may if necessary be used to calibrate or correct the output from the measuring sensor in relation to a selected parameter or parameters.

Viewed from a further aspect, the invention provides a fibre laser sensor system, comprising at least two fibre lasers written into respective optical fibres, at least one of which is a birefringent fibre,

and detecting means configured to generate beat signals dependent upon the birefringence of said at least one fibre, the detecting means preferably also generating beat signals between the laser outputs, which beat frequencies are used to derive a measurement of at least one parameter.

As discussed above, in this aspect, one of the fibre lasers may constitute a reference laser which is located in a separate environment from a measuring laser. Alternatively, pairs of lasers may be located in the same environment, in differently configured fibres.

In a different set of embodiments, the sensing system is based on a passive device, preferably a passive fibre Bragg grating, most preferably a π-phase-shifted FBG. In this case, at least the reference sensor is provided in a birefringent fibre, and the two resonances corresponding to the birefringent axes of the fibre are measured.

This measurement may be carried out in a manner which is generally similar to that described in US 6,097,487, in which a comb spectrum derived from part of the light from a tunable light source is generated, and this comb spectrum provides an accurate frequency/wavelength scale for measurement of the spacings between the spectral notches in the birefringent output of the fibre. Examples of suitable tunable light sources are tunable single polarization lasers or a tunable side band of an RF modulated laser.

In a preferred such system, the comb spectrum is generated by an interferometer which receives a part of the light from the tunable source, and is also effective to reduce the effect of noise in the output of the tunable source, which can otherwise limit the resolution of spectral measurements.

Such a system provides an improved apparatus for measurement of reflection and absorbent spectra enabling particularly high resolution.

Hence, a still further aspect of the invention provides a system for spectral analysis, comprising a tunable light source, part of the light from which is passed to an optical device providing a device spectrum to be measured, and part of the light from which is passed to an interferometer which generates a comb spectrum, such comb spectrum being used to provide a linearised frequency scale for measurement of the device spectrum, whereby the effect of noise in the tunable light source is reduced, and a further part of the light from the source being passed to a birefringent reference grating which provides an absolute wavelength reference. The interferometer is preferably a Michelson interferometer which acts as a frequency discriminator as well as a comb spectrum generator. The interferometer has a large path imbalance. The reference grating is preferably a π-phase shifted FBG.

Alternatively, measurements may be carried out by locking frequencies of additional fibre laser sources to the resonance frequencies and measuring electrical beat frequencies between these laser frequencies.

A further aspect of the invention provides a fibre optic sensing system comprising at least two passive π-phase shifted FBG sensors written into respective fibres, at least one of which is a birefringent fibre, and the detecting means including means for measuring the frequency splitting between two resonances of the birefringent fibre, such splitting being used to derive a reference signal by the detecting means. As discussed above, the system preferably also measures the frequency splitting between the reference and measuring sensor outputs.

As also discussed above, it is preferred, but not essential, that both FBG's are written into birefringent fibres, in which case the detecting means may additionally be configured to measure the frequency splitting between the resonances of each birefringent

fibre.

A further aspect of the invention provides a detecting means for use with a fibre optic sensing system, the detecting means including means for receiving and analysing optical outputs from at least two fibre optic sensors, which outputs have substantially the same nominal operating wavelength, and at least one of the outputs having birefringent components, the analysing means operating by comparing said outputs from the respective sensors to derive an output signal indicative of at least one parameter sensed by at least one of the sensors in use.

A further aspect of the invention provides a method of sensing a parameter through the use of a fibre optic measuring sensor in which the optical output from the sensor is compared with the optical output from a reference sensor, the reference sensor being provided in a birefringent fibre and said sensors having substantially the same nominal operating wavelength.

A still further aspect of the invention provides a dual parameter fibre optic sensing system, comprising a pair of birefringent optical fibres each having at least one sensor configured to provide a birefringent optical output dependent upon a respective parameter, and detecting means having signal processing means adapted to provide an electrical output signal indicative of the birefringence of each of said fibre.

In this, and some other embodiments of some of the above aspects of the invention, the sensors may instead be configured to operate with substantially different operating wavelengths to avoid cross-talk in the detection means.

Some preferred embodiments of the invention will now be described, by way of example, with reference to the accompanying drawings, in which:

Figure 1a shows a preferred embodiment of a two-parameter sensor system comprising two dual-polarisation

fibre DFB lasers;

Figure 1b shows the optical spectrum from the two dual-polarisation fibre DFB lasers and the resulting electrical beat spectrum for each of the two lasers and the beat frequency between the two lasers;

Figure 2 shows an alternative configuration where both lasers are placed together in a sensor probe to provide dual-parameter sensing;

Figure 3 shows a preferred embodiment of a distributed two-parameter sensor system which consists of linear arrays of wavelength multiplexed fibre DFB lasers with the reference DFB lasers placed side-by-side with the corresponding sensor DFB lasers;

Figure 4a shows a preferred embodiment of a two-parameter sensor system comprising passive birefringent π-phase-shifted FBG measured with a narrow band tuneable laser polarised along each of the two polarisation axes, respectively;

Figure 4b shows the reflection spectrum of the two orthogonal polarisations of a birefringent π-phase-shifted FBG measured with a narrowband tuneable laser polarised along each of the two polarisation axes;

Figure 4c shows the reflection spectrum of a birefringent π-phase-shifted FBG measured with a narrow band tuneable laser polarised at 45° relative to the birefringent axes of the FBG;

Figure 4d shows the measured reflection spectra of the measuring and reference sensor π-phase-shifted FBGs, and illustrates how the measured resonance frequencies can be used to measure two independent parameters such as temperature and pressure or temperature and strain;

Figure 5 shows an alternative system in which both the FBGs are placed together in a sensor probe to provide dual parameter sensing;

Figure 6 shows an embodiment of distributed two-parameter sensor system based on linear arrays of wavelength multiplexed π-phase-shifted FBGs; and

Figure 7 illustrates a spectra measured through a specific setup according to Figure 4a.

Figure 1a shows a two-parameter fibre optic sensor system based on two birefringent i.e. dual-polarisation fibre DFB laser sensors, where two independent parameters are determined from the frequency splitting and the absolute optical frequency of one of the fibre DFB lasers 1, acting as the measuring sensor, using the other laser 2 as a reference sensor. Laser 1 is contained in a sensing probe house 3. The two lasers 1 and 2 are spliced to the two output ports 4 and 5 of a polarisation maintaining 2x2 coupler (PMC) 6 such that the two orthogonally polarised laser frequencies emitted from each laser are guided in each of the two orthogonal polarisation axes of the polarisation maintaining output ports 4 and 5 of the PMC. The fibre lasers, which have the same nominal operating wavelength, are pumped by a semiconductor diode 7, which can have a pump wavelength of 980nm or 1480nm, through an optical isolator 8 spliced to one of the input ports 9 of the PMC.

The two orthogonally polarised laser frequencies emitted from each laser, ν_1 and $\nu_1+\Delta\nu_1$ from laser 1 and the ν_2 and $\nu_2+\Delta\nu_2$ from laser 2 (see Fig. 1b), are guided through the PMC to the port 10, which is spliced to polarising optical isolator 12 with polarisation maintaining fibre pigtails. The splice 11 is arranged with the polarisation axes of the two fibres oriented at 45° such that orthogonally polarised laser light is mixed.

The laser light passing the isolator 12 is incident on a detector 13 followed by an electrical receiver circuit 14 with electrical receiver bandwidth BW, where the orthogonally polarised laser light is mixed to generate three electrical beat frequencies $f_1 = \Delta\nu_1$, $f_2 = \Delta\nu_2$ and $f_3 = \Delta\nu_{12}$ (see Fig. 1b), where f_1, f_2, $f_3 < BW$. The beat frequency f_3 is a measure of the laser frequency of laser 1 relative to the laser frequency of reference

laser 2. In this case $|\nu_2-(\nu_1+\Delta\nu_1)|$ should be < BW to ensure a beat signal between the two lasers. The electrical beat frequencies f_1, f_2, and f_3 provide exact information about the two parameters to be measured, and the beat frequency f_2 is used to determine the temperature of the reference laser and hence the exact reference frequency. Note that both lasers must be kept free from strain other than strain resulting from a parameter to be measured, since strain strongly affects the laser frequencies. The measurement of f_3 can be used to control the temperature of the reference laser 2 inside an oven 15 using a feedback circuit 16 such that the nominal operating wavelengths of the sensors remain the same.

The measuring sensor 1 can be configured to be responsive to a particular measurand in a known manner, such as by being provided with a reactive element or coating arranged to establish strain in the sensor and thereby change the output frequency upon exposure to a measurand.

Figure 2 shows sensor and reference dual-polarisation fibre DFB lasers 1 and 2, having different sensitivity to the two parameters to be measured, for example pressure and temperature, placed together in a sensing probe housing 3 to provide dual-parameter sensing. The two lasers 1 and 2 are again spliced to the two output ports 4 and 5 of a polarisation maintaining 2x2 coupler (PMC) 6 such that the two orthogonally polarised laser frequencies emitted from each laser are guided in each of the two orthogonal polarisation axes of the polarisation maintaining output ports 4 and 5 of the PMC. The fibre lasers are pumped by a semiconductor diode 7, which can have a pump wavelength of 980nm or 1480nm, through an optical isolator 8 spliced to one of the input ports 9 of the PMC. The two orthogonally polarised laser frequencies emitted from each laser, ν_1 and $\nu_1+\Delta\nu_1$ from laser 1 and ν_2

and $\nu_2+\Delta\nu_2$ from laser 2 (see Fig. 1b), are guided through the PMC to the port 10, which is spliced to polarising optical isolator 12 by means of polarisation maintaining fibre pigtails. The splice 11 is carried out with the polarisation axes of the two fibres oriented at 45° such that orthogonally polarised laser light is mixed. The laser light passing the isolator 12 is incident on a detector 13 followed by an electrical receiver circuit 14 with electrical receiver bandwidth BW, where the orthogonally polarised laser light is mixed to generate two electrical beat frequencies $f_1 = \Delta\nu_1$ and $f_2 = \Delta\nu_2$ (see Fig. 1b), where f_1 and f_2 < BW. Note that $\nu_2 - (\nu_1+\Delta\nu_1)$ can, in this embodiment, be > BW to prevent a beat signal being generated between the two lasers. The electrical beat frequencies f_1 and f_2 provide exact information about the two parameters to be measured, provided the two lasers are under equal temperature and strain conditions.

Alternatively, a beat signal may additionally be measured between the lasers. Such a signal can be used to monitor, e.g. anomalies in the sensor probe.

Figure 3 shows a distributed sensing system where a series of dual-polarisation fibre DFB lasers 1 and 2 contained in pairs in sensor probes 3 are wavelength multiplexed along two different polarisation maintaining fibres with laser wavelengths λ_i, i=1,2,3,4. The two fibres are spliced in the two output ports 4 and 5 of a polarisation maintaining 2x2 coupler (PMC) 6 such that the two orthogonally polarised laser frequencies emitted from each laser are guided in each of the two orthogonally polarisation axes of the polarisation maintaining output ports 4 and 5 of the PMC. The fibre lasers are pumped by a semiconductor diode 7, which can have a pump wavelength of 980nm or 1480nm, through an optical isolator 8 spliced to one of the input ports 9 of the PMC. The two orthogonally polarised laser frequencies emitted from each laser are guided through

the PMC to the port 10, which is spliced to polarising optical isolator 12 with polarisation maintaining fibre pigtails, the splice 11 being achieved with the polarisation axes of the two fibres oriented at 45° such that orthogonally polarised laser light is mixed. The laser light passing the isolator 12 is passed through a wavelength demultiplexer 17 which splits the light from the different wavelength multiplexed lasers with wavelengths λ_i, i=1,2,3,4 onto separate detectors 18 followed by electrical receiver circuits 14 with electrical receiver bandwidth BW. The orthogonally polarised laser light is mixed to generate electrical beat frequencies f_{i1} and f_{i2}, i=1,2,3,4, where f_{i1} and f_{i2} < BW. The wavelength difference between the respective wavelength multiplexed pairs of reference and sensing lasers must be large enough to eliminate cross-talk between the different laser pairs, typically >1nm.

Again, in an alternative embodiment, beat frequencies may additionally be measured between the lasers.

Figure 4a shows a preferred embodiment of a two-parameter sensor system based on two passive birefringent π-phase-shifted FBGs, where two independent parameters are determined by measuring both the frequency splitting and the absolute optical frequency of one of the π-phase-shifted FBGs 101 acting as the measuring sensor, using the other FBG 102 as a reference sensor. FBG 101 is contained in a sensing probe house 103, where the FBG should be eliminated from strain and rapid temperature variations. The two FBGs are illuminated by a frequency swept narrowband laser 104, which preferentially is a strain tuned single polarisation fibre DFB laser, which is frequency swept over a frequency range covering the orthogonally polarised resonance frequencies of both FBGs 101 and 102. The reference FBG 102 is kept free from strain and its temperature is controlled inside an oven 105 to

minimise the wavelength separation between the two FBGs, and hence the required laser tuning range , and to minimise temperature variations of the reference FBG.

The laser light passes an optical isolator 106 before it is split by a direction coupler 107, where one part is again split by a 50/50 coupler 108 and directed to FBG 101 and 102 through polarisation controller (PC) 109 and 50/50 coupler 111, and PC 116 and 50/50 coupler 112, respectively. The polarisation controllers are used to align the polarisation of the laser light at 45° relative to the two orthogonal polarisation axes of each FBG. The second part of the light split by coupler 107 is passed to a reference Michelson interferometer 113, which is packaged such that rapid temperature fluctuations are minimised. The interferometer consists of a 50/50 coupler 114, two fibre arms 115 and 116, with a path imbalance ΔL, which is typically 10-100m, with Faraday mirrors 117 and 118 at the end of each fibre arm.

The use of Faraday mirrors eliminates polarisation fading in the reference interferometer. The reflected light from the reference interferometer 113 is passed to a reference detector 119. The detected reference signal consists of a pulse train 120 with equidistant peaks corresponding to the free spectral range of the reference interferometer. The reflected light from the FBGs 101 and 102 are directed to detector 121 and 122 through coupler 111 and isolator 123, and coupler 112 and isolator 124, respectively. The detector signals are the result from scanning the two orthogonally polarised spectra of the high finesse π-phase-shifted FBG, illustrated in Fig. 4b at 45°, with solid and dotted lines, respectively. The resulting spectrum is shown in Fig. 4c, clearly showing two narrowband dips in the spectrum, which separation is directly proportional to the fibre birefringence.

By comparing the detector signals from detector 121

and 122, corresponding to the sensor FBG 101 and reference FBG 102, which are shown schematically in Fig. 4d around the narrowband dips, and using the reference signal 120 from reference detector 119 as a frequency scale to linearise the laser frequency scan, the frequency splitting of the sensor and reference FBG, corresponding to the time splitting $\Delta\tau_{sens}$ and $\Delta\tau_{ref}$ in Fig. 4d, as well as the relative frequency splitting of the two spectra, corresponding to $\Delta\tau$ in Fig. 4d, can be determined with high accuracy. This provides an accurate dual parameter sensing scheme, where the two parameters can be pressure and temperature of the sensor FBG.

Figure 5 shows a preferred embodiment of a two-parameter sensor system based on two passive birefringent π-phase-shifted FBGs, with exactly the same configuration as in Fig. 4a, only with the difference that the two FBGs 101 and 102 are placed side-by-side inside the sensor housing 103, and that the two independent parameters are determined by measuring only the individual frequency splitting of each FBG, and not their relative frequency separation. This has the advantage of eliminating errors due to strain effects (in the case of pressure and temperature measurements), provided both FBGs experience the same strain.

Figure 6 shows a preferred embodiment of a distributed two-parameter sensor system based on linear arrays of wavelength multiplexed π-phase-shifted FBGs. The configuration is the same as in Fig. 4a and Fig. 5, only with the difference that the frequency swept laser source 4' has n output wavelengths (here n=4) with a spacing of typically >1nm which are swept in parallel to cover both n sensor FBGs 1 and n reference FBGs 2 with different Bragg wavelengths matching the different laser wavelengths. Preferably the laser array consists of n strain tuned singled polarisation fibre DFB lasers along one fibre or in n parallel fibres pumped with one pump

diode laser. The reflected light from the FBGs 101 and 102 is directed to separate detectors 121 and 122, through wavelength demultiplexers 126 and 127, for the sensor and reference wavelengths, respectively. Only one of the laser wavelengths is directed to the reference Michelson interferometer 113 by using a WDM coupler or filter 125, which is sufficient to linearise the wavelength sweep provided that all wavelengths are swept equally.

In an alternative to the embodiment shown in Figure 6, a single tunable laser tuning all sensor wavelengths may be used. In this case only a single reference sensor may be used.

Figures 7a and b, show the simultaneously measured reflection and transmission spectra of a birefringent π-phase-shifted FBG (device under test - DTU) 101 using a setup very similar to the one illustrated in Fig. 4a, illustrating how the setup can be used as an ultra-high-resolution optical spectrum analyser for characterisation of wavelength dependent optical components such as FBGs.

In a particular embodiment, the frequency swept narrowband laser 104 shown in Fig. 4a is a strained tuned single polarisation fibre DFB laser polarised at 45° relative to the polarisation eigenaxes of the FBG. The reference Michelson interferometer 113 has a path length imbalance of ca. 30m, which gives sinusoidal fringes (comb spectrum) with a periodicity of ca. 3MHz. The reference fringes are used to sample the laser frequency and hence linearise the frequency scale and reduce the effect of the laser frequency noise on the measured spectra. The transmission spectrum of the FBG 101 is measured with a separate optional detector 125 at the output end of the FBG. Fig. 7a shows the measured spectrum over the full bandwidth of the FBG (ca. 16GHz or 0.13nm), while Fig. 7b shows a close-up of the two orthogonally polarised resonances, which have splitting

of 270MHz and a bandwidths of ca. 10MHz, which is fully resolved with the measurement setup. By use of the reference FBG the absolute wavelengths of the spectrum can be determined.

Claims:

1. A fibre optic sensor system, comprising at least one measuring sensor providing an optical output dependent upon one or more parameters to be measured, and at least one reference sensor providing a reference output for comparison with the measuring sensor output, wherein the reference sensor is provided in a birefringent fibre, and the system includes a detecting means whereby a reference beat signal is derived by measuring the optical frequency splitting between frequency components in different polarisation planes of the reference sensor output, a further beat signal being generated between the measuring and reference sensor outputs, such beat signals being used to derive a measurement of one or more parameters.

2. A fibre optic sensor system including measuring and reference sensors written into respective optical fibres, in which at least the reference sensor is written into a birefringent fibre, and the system further includes a detecting means which operates by generating a beat frequency derived from the output of the reference sensor.

3. A system as claimed in claim 1 or 2 adapted to use a beat frequency derived from the reference sensor output and a beat frequency derived from a comparison between the measuring sensor output and the reference sensor output to derive an indication of at least one parameter of interest without the need directly to measure the absolute frequency of either sensor by optical means.

4. A system as claimed in claim 1, 2 or 3 wherein the measuring sensor is also provided in a birefringent fibre such that a beat frequency derived from this

sensor can be used to measure a different parameter.

5. A system as claimed in any preceding claim comprising a plurality of measuring sensors at different nominal wavelengths, said measuring sensors being multiplexed along a common respective fibre with a single reference sensor provided in a different fibre or with multiple reference sensors.

6. A system as claimed in any preceding claim wherein said measuring and reference sensors have the same nominal operating wavelength.

7. A system as claimed in any preceding claim wherein said reference sensor is located in an oven whose temperature is controlled in such a way that the reference sensor has the same nominal operating wavelength as the measuring sensor.

8. A system as claimed in any of claims 1 to 6 wherein said reference sensor is placed close to the measuring sensor.

9. A system as claimed in any preceding claim wherein said reference and measuring sensors are in the form of active fibre lasers such that the output of the birefringent reference laser consists of spaced spectral peaks in different polarisation planes.

10. A system as claimed in claim 9 wherein said active fibre lasers are fibre distributed feedback lasers.

11. A system as claimed in claim 9 or 10 wherein the measuring laser is also written into a birefringent fibre.

12. A system as claimed in any preceding claim

comprising detecting means arranged to operate by generating beat frequencies in the electrical domain.

13. A fibre laser sensor system comprising at least two fibre lasers written into respective optical fibres, at least one of which is a birefringent fibre, and detecting means configured to generate beat signals dependent upon the birefringence of said at least one fibre.

14. A system as claimed in claim 13 wherein said detecting means is also arranged to generate beat signals between the laser outputs, such that beat signals can be used to derive a measurement of at least one parameter.

15. A system as claimed in claim 13 or 14 wherein one of said fibre lasers constitutes a reference laser which is located in a separate environment from a measuring laser.

16. A system as claimed in claim 13 or 14 wherein said two fiber lasers are differently configured and are located in the same environment.

17. A system as claimed in any of claims 1 to 8 wherein at least said measuring sensor is a passive device.

18. A system as claimed in claim 17 wherein said passive device comprises a passive fibre Bragg grating.

29. A system as claimed in claim 18 wherein said measuring sensor comprises a π-phase-shifted fibre Bragg grating.

20. A system as claimed in claim 17, 18 or 19 wherein at least the reference sensor is provided in a

birefringent fibre having two birefringent axes, said system further comprising means for measuring two resonances corresponding to the birefringent axes of the fibre.

21. A system as claimed in any of claims 17 to 20 comprising a tunable light source and means for deriving a comb spectrum from part of the light therefrom.

22. A system as claimed in claim 21 wherein said means for deriving a comb spectrum comprises an interferometer arranged to receives a part of the light from the tunable source.

23. A system for spectral analysis, comprising a tunable light source, part of the light from which is passed to an optical device providing a device spectrum to be measured, and part of the light from which is passed to an interferometer which generates a comb spectrum, such comb spectrum being used to provide a linearised frequency scale for measurement of the device spectrum, whereby the effect of noise in the tunable light source is reduced, and a further part of the light from the source being passed to a birefringent reference grating which provides an absolute wavelength reference.

24. A system as claimed in claim 22 or 23 wherein said interferometer is a Michelson interferometer arranged to act as a frequency discriminator as well as a comb spectrum generator.

25. A system as claimed in claim 23 or claim 24 when dependent on claim 23 wherein said reference grating is a π-phase shifted fiber Bragg grating.

26. A system as claimed in claim 23, or claim 24 or 25 when dependent on claim 23, comprising means for

carrying out a measurement by locking frequencies of additional fibre laser sources to the resonance frequencies and means for measuring electrical beat frequencies between these laser frequencies.

27. A fibre optic sensing system comprising at least two passive π-phase shifted FBG sensors written into respective fibres, at least one of which is a birefringent fibre, and the detecting means including means for measuring the frequency splitting between two resonances of the birefringent fibre, such splitting being used to derive a reference signal by the detecting means.

28. A system as claimed in claim 27 comprising means for measuring a frequency splitting between the reference and measuring sensor outputs.

29. A system as claimed in claim 27 or 28 wherein both of said FBG's are written into birefringent fibres.

30. A system as claimed in claim 29 wherein said detecting means is additionally configured to measure the frequency splitting between the resonances of each birefringent fibre.

31. A detecting means for use with a fibre optic sensing system, the detecting means including means for receiving and analysing optical outputs from at least two fibre optic sensors, which outputs have substantially the same nominal operating wavelength, and at least one of the outputs having birefringent components, the analysing means operating by comparing said outputs from the respective sensors to derive an output signal indicative of at least one parameter sensed by at least one of the sensors in use.

32. A dual parameter fibre optic sensing system, comprising a pair of birefringent optical fibres each having at least one sensor configured to provide a birefringent optical output dependent upon a respective parameter, and detecting means having signal processing means adapted to provide an electrical output signal indicative of the birefringence of each of said fibre.

33. A system as claimed in claim 32 wherein said sensors are configured to operate with substantially different operating wavelengths.

34. A method of sensing a parameter through the use of a fibre optic measuring sensor in which the optical output from the sensor is compared with the optical output from a reference sensor, the reference sensor being provided in a birefringent fibre and said sensors having substantially the same nominal operating wavelength.

35. A method of sensing a parameter using two or more fibre optic sensors, comprising using an output from a reference sensor provided in a birefringent fibre to derive a beat signal for comparison with an output from a measuring sensor provided in a second fibre.

36. A method as claimed in claim 35 comprising using a beat frequency derived from the reference sensor output and a beat frequency derived from a comparison between the measuring sensor output and the reference sensor output to derive an indication of at least one parameter of interest without the need directly to measure the absolute frequency of either sensor by optical means.

37. A method as claimed in claim 35 or 36 comprising measuring a frequency splitting in relation to the optical output from said birefringent reference sensor

thereby providing an indication of temperature of the reference sensor.

38. A method as claimed in claim 37 comprising comparing said optical output with a frequency component of the measuring sensor and deriving a measurement of temperature at the measuring sensor.

39. A method as claimed in claim 37 comprising comparing said optical output with a frequency component of the measuring sensor; using said indication of temperature at the reference sensor to correct the output of the measuring sensor for variations in temperature; and, deriving another parameter from the measuring sensor.

40. A method as claimed in any of claims 35 to 39 wherein the reference sensor has the same nominal operating wavelength as the measuring sensor.

41. A method as claimed in any of claims 35 to 40 comprising providing said measuring sensor in a second birefringent fibre, and performing a measurement in relation to a birefringent response of said second birefringent fibre, said measurement being based on the absolute frequency of the response, and/or on the spacing of spectral peaks or notches in mutually orthogonal polarisation planes.

42. A method as claimed in claim 41 comprising comparing said spacing with a birefringent wavelength spacing derived from the reference sensor, and using the reference sensor to calibrate or correct the output from the measuring sensor.

43. A method as claimed in claim 41 or 42 comprising using the absolute frequency of the measuring sensor

output for measurements.

44. A method as claimed in claim 43 comprising: measuring the absolute frequency of the measuring sensor, the absolute frequency of the reference sensor, and the birefringent frequency splitting of each of said sensors; and determining two parameters, such as pressure, temperature, or biochemical parameters therefrom.

45. A method as claimed in any of claims 35 to 44 comprising deriving the absolute frequency of the measuring sensor from beats generated between the measuring and reference sensor outputs.

46. A method of measuring one or more parameters using fibre optic sensor system, comprising at least one measuring sensor providing an optical output dependent upon said one or more parameters to be measured, and at least one reference sensor providing a reference output for comparison with the measuring sensor output, wherein the reference sensor is provided in a birefringent fibre, and the system includes a detecting means; said method comprising deriving a reference beat signal by measuring the optical frequency splitting between frequency components in different polarisation planes of the reference sensor output, generating a further beat signal being between the reference measuring and reference sensor outputs, and using said beat signals to derive a measurement of said one or more parameters.

47. A method as claimed in claim 46 comprising:

deriving a first beat frequency derived from the reference sensor output;

deriving a second beat frequency from a comparison between the measuring sensor output and the reference sensor output; and

using said first and second beat frequencies to derive an indication of at least one parameter of interest without the need directly to measure the absolute frequency of either sensor by optical means.

48. A method as claimed in claim 46 or 47 wherein the measuring sensor is also provided in a birefringent fibre the method further comprising deriving a beat frequency from said measuring sensor and using said beat frequency to measure a different parameter.

49. A method as claimed in claim 46, 47 or 48 wherein said measuring and reference sensors have the same nominal operating wavelength.

50. A method as claimed in any of claims 46 to 49 comprising locating said reference sensor in an oven and controlling the temperature of said oven in such a way that the reference sensor has the same nominal operating wavelength as the measuring sensor.

51. A method as claimed in any of claims 46 to 49 comprising placing said reference sensor close to the measuring sensor.

52. A method as claimed in any of claims 46 to 51 comprising providing a detecting means and generating beat frequencies in the electrical domain using said detecting means.

53. A method of measuring at least one parameter using a fibre laser sensor system having at least two fibre lasers written into respective optical fibres, at least one of which is a birefringent fibre, and a detecting means said method comprising using said detecting means to generate beat signals dependent upon the birefringence of said at least one birefringent fibre.

54. A method as claimed in claim 53 comprising generating beat signals between the laser outputs, and using said beat frequencies to derive a measurement of at least one parameter.

55. A method as claimed in claim 53 or 54 comprising designating one of said fibre lasers as a reference laser and locating said reference laser in a separate environment from a measuring laser.

56. A method as claimed in claim 53 or 54 wherein said two fiber lasers are differently configured, comprising locating said two fiber lasers in the same environment.

57. A method as claimed in any of claims 35 to 52 wherein at least the reference sensor is provided in a birefringent fibre having two birefringent axes, said method further comprising measuring two resonances corresponding to the birefringent axes of the fibre.

58. A method as claimed in any of claims 35 to 52 or claim 57 comprising providing a tunable light source and deriving a comb spectrum from part of the light therefrom.

59. A method as claimed in claim 58 comprising measuring spacings between the spectral notches in the birefringent output of the fibre using the comb spectrum as an accurate frequency/wavelength scale.

60. A method of spectral analysis, comprising providing a tunable light source, passing part of the light therefrom which to an optical device providing a device spectrum to be measured, passing part of the light from the tunable light source to an interferometer, thereby generating a comb spectrum, using said comb spectrum to provide a linearised

frequency scale for measurement of the device spectrum, whereby the effect of noise in the tunable light source is reduced, and passing a further part of the light from the tunable light source to a birefringent reference grating, thereby providing an absolute wavelength reference.

61. A method as claimed in claim 60 comprising providing a Michelson interferometer as said interferometer and arranging the Michelson interferometer to act as a frequency discriminator as well as a comb spectrum generator.

62. A method as claimed in claim 60 or 61 comprising carrying out a measurement by locking frequencies of additional fibre laser sources to the resonance frequencies and measuring electrical beat frequencies between these laser frequencies.

63. A method of sensing using at least two passive π-phase shifted FBG sensors written into respective fibres, at least one of which is a birefringent fibre, and a detecting means, the method comprising measuring the frequency splitting between two resonances of the birefringent fibre, and said detecting means using said splitting to derive a reference signal by the.

64. A method as claimed in claim 63 comprising measuring a frequency splitting between the outputs of said fibres.

65. A method as claimed in claim 63 or 64 wherein both of said π-phase shifted FBG sensors are written into birefringent fibres, the method comprising measuring the frequency splitting between the resonances of each birefringent fibre.

66. A method of deriving an output signal indicative of at least one parameter comprising: providing at least two fibre optic sensors providing optical outputs with substantially the same nominal operating wavelength, at least one of said outputs having birefringent components; receiving and analysing said optical outputs; and comparing said optical outputs to derive said output signal indicative of the at least one parameter.

67. A fibre optic sensor system, comprising at least one measuring sensor providing an optical output dependent upon one or more parameters to be measured, and at least one reference sensor providing a reference output for comparison with the measuring sensor output, wherein the reference sensor is provided in a birefringent fibre, and the system includes a detecting means whereby a reference frequency difference signal is derived by measuring the optical frequency splitting between frequency components in different polarisation planes of the reference sensor output, a further frequency difference signal being generated between the measuring and reference sensor outputs, such frequency difference signals being used to derive a measurement of one or more parameters.

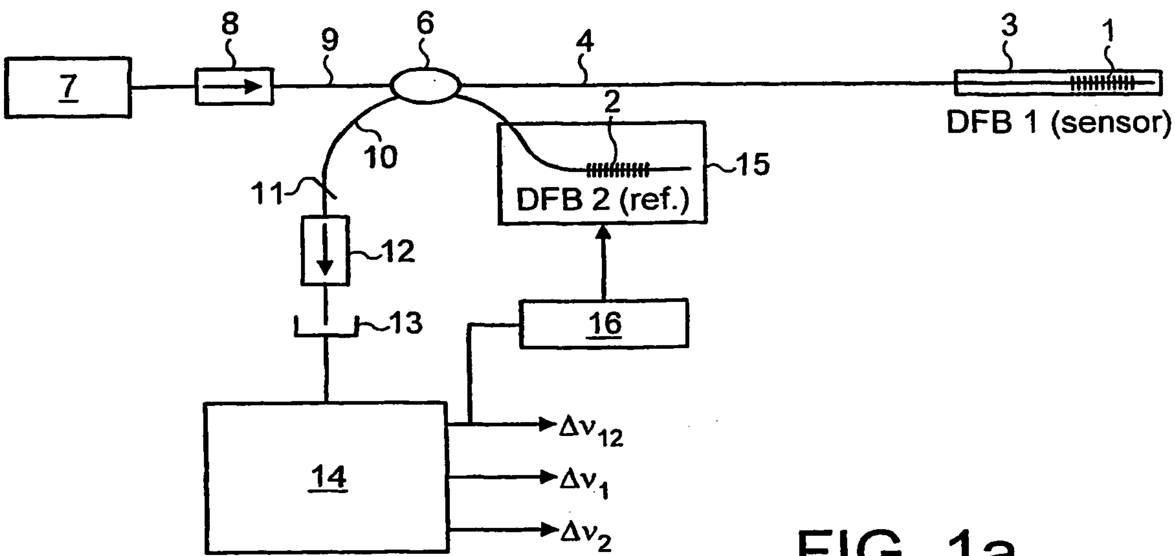

8
9
6
4
3
1
7
DFB 1 (sensor)
2
10
15
11
DFB 2 (ref.)
12
13
16
14
$\Delta\nu_{12}$
$\Delta\nu_1$
$\Delta\nu_2$

FIG. 1a

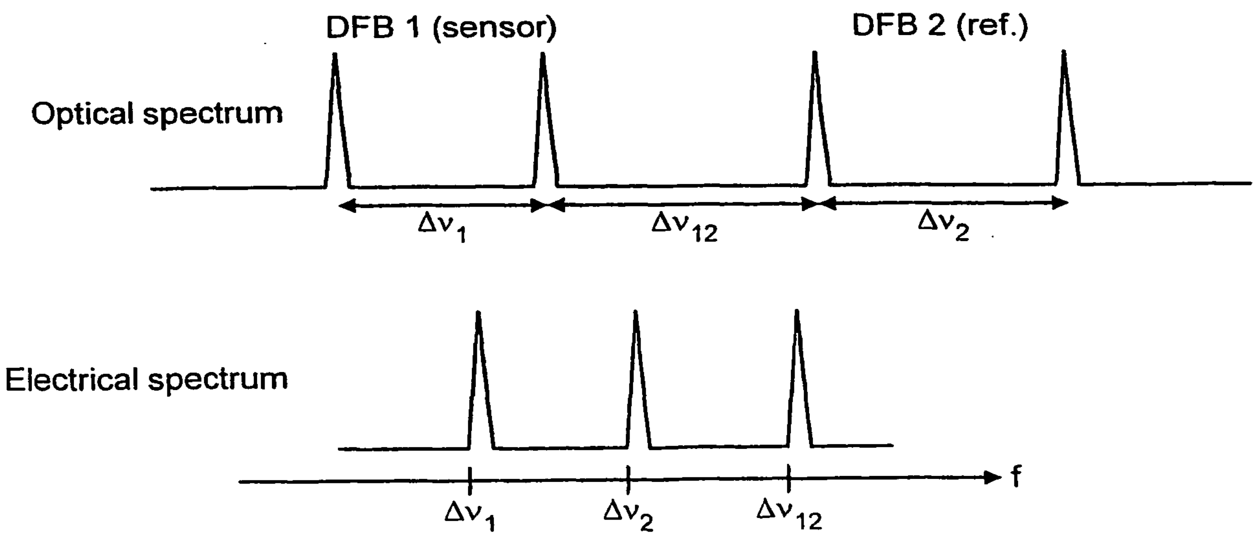

DFB 1 (sensor)
DFB 2 (ref.)
Optical spectrum
$\Delta\nu_1$
$\Delta\nu_{12}$
$\Delta\nu_2$
Electrical spectrum
f
$\Delta\nu_1$
$\Delta\nu_2$
$\Delta\nu_{12}$

FIG. 1b

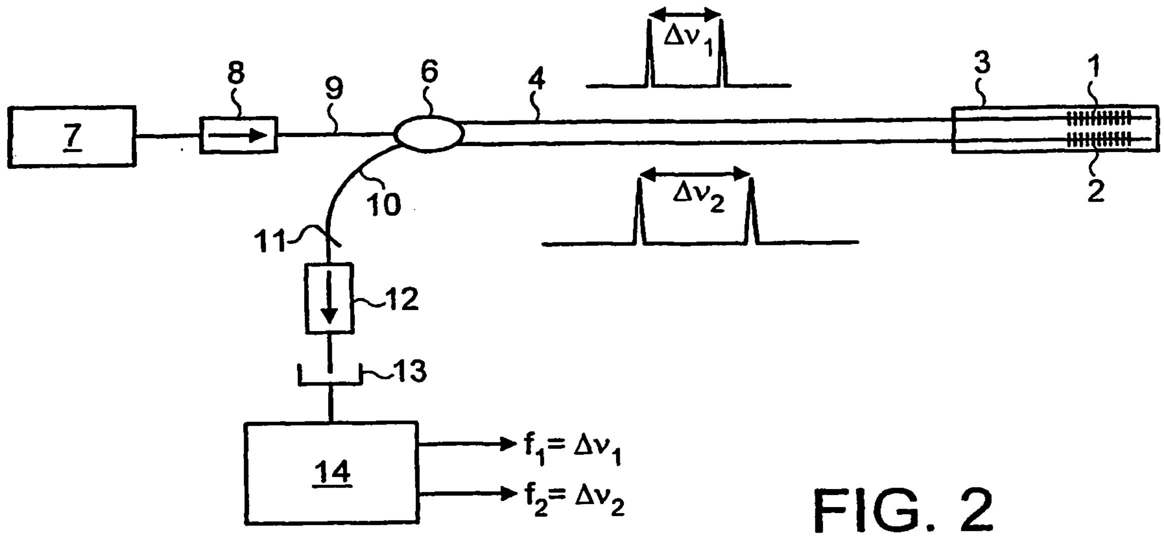
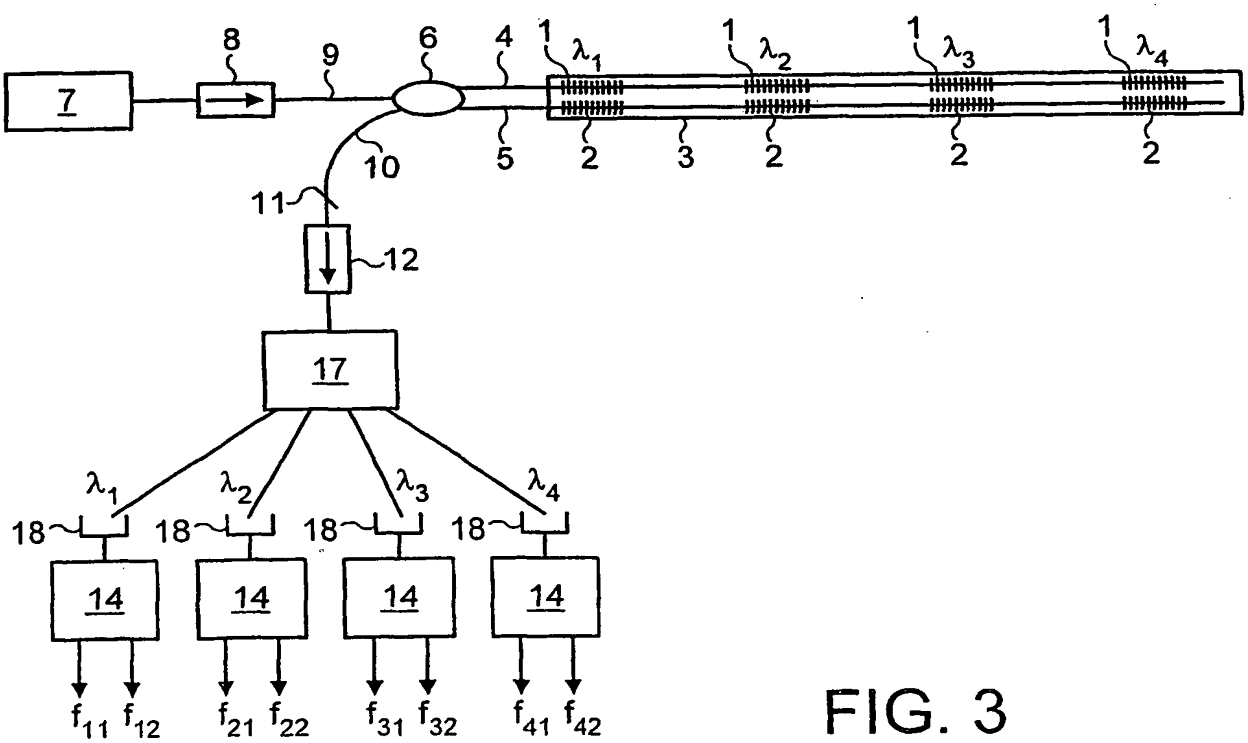

$\Delta\nu_1$
8
9
6
4
3
1
7
10
$\Delta\nu_2$
2
11
12
13
14
$f_1 = \Delta\nu_1$
$f_2 = \Delta\nu_2$

FIG. 2


8
9
6
4
1
λ_1
1
λ_2
1
λ_3
1
λ_4
7
10
5
2
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2
2
2
11
12
17
λ_1
λ_2
λ_3
λ_4
18
18
18
18
14
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14
f_{11} f_{12}
f_{21} f_{22}
f_{31} f_{32}
f_{41} f_{42}

FIG. 3

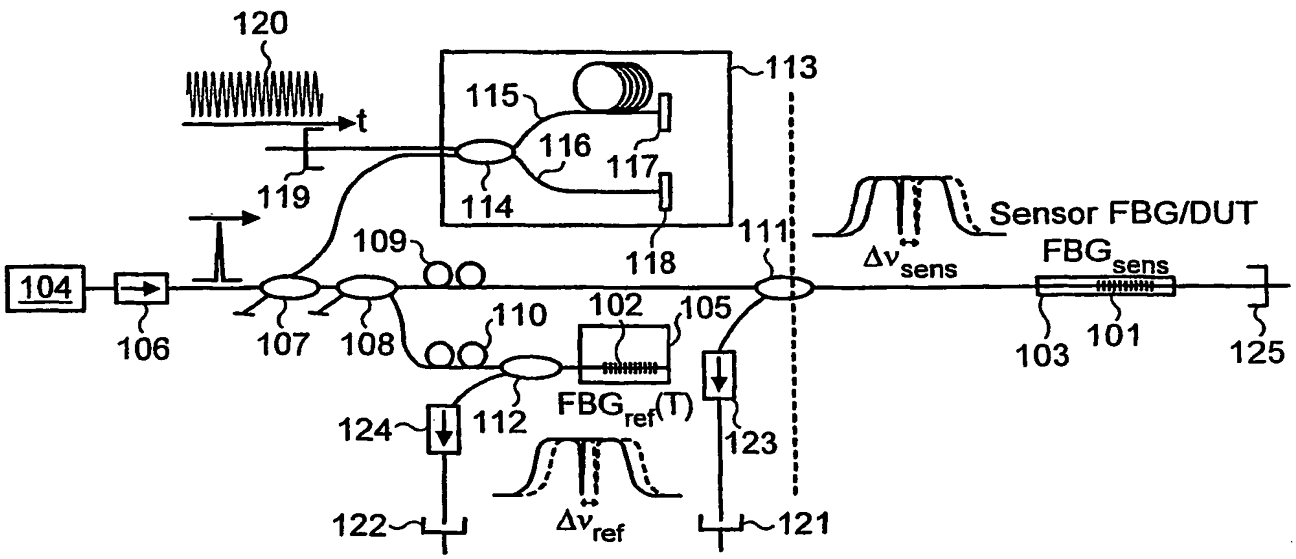
120
t
113
115
116
117
119
114
118
109
111
Sensor FBG/DUT
FBG$_{sens}$
$\Delta\nu_{sens}$
104
106
107
108
110
102
105
103
101
125
124
112
FBG$_{ref}$(T)
123
122
$\Delta\nu_{ref}$
121

FIG. 4a

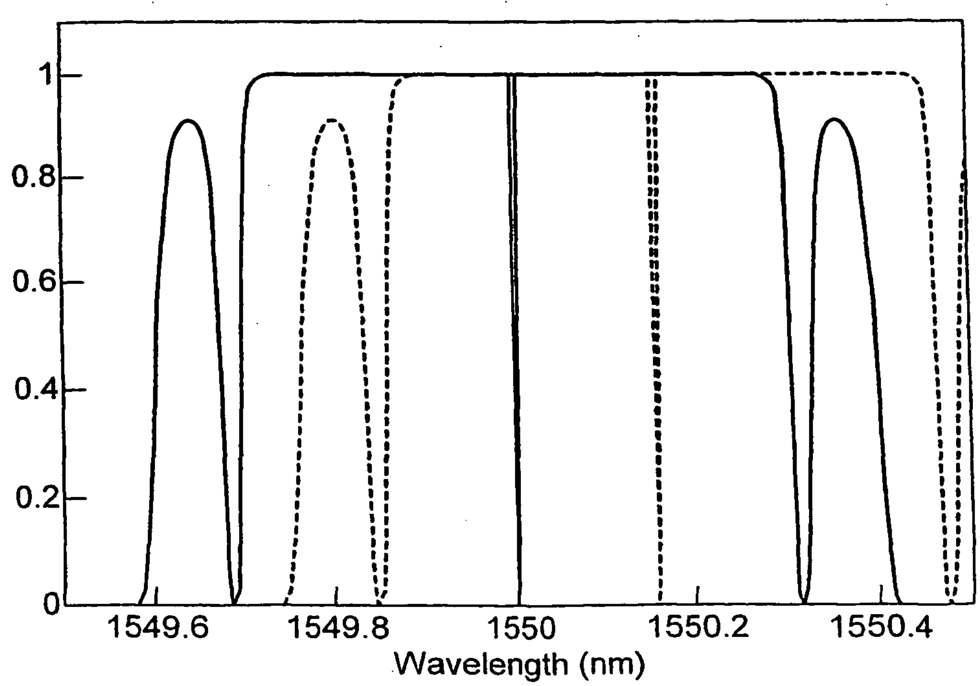
1
0.8
0.6
0.4
0.2
0
1549.6
1549.8
1550
1550.2
1550.4
Wavelength (nm)

FIG. 4b

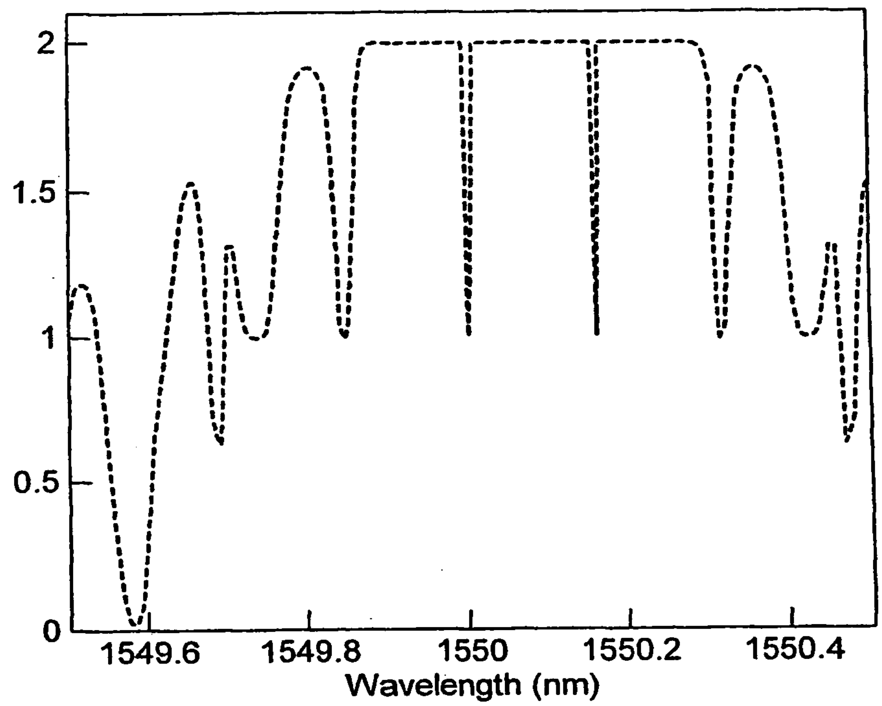
2
1.5
1
0.5
0
1549.6
1549.8
1550
1550.2
1550.4
Wavelength (nm)

FIG. 4c

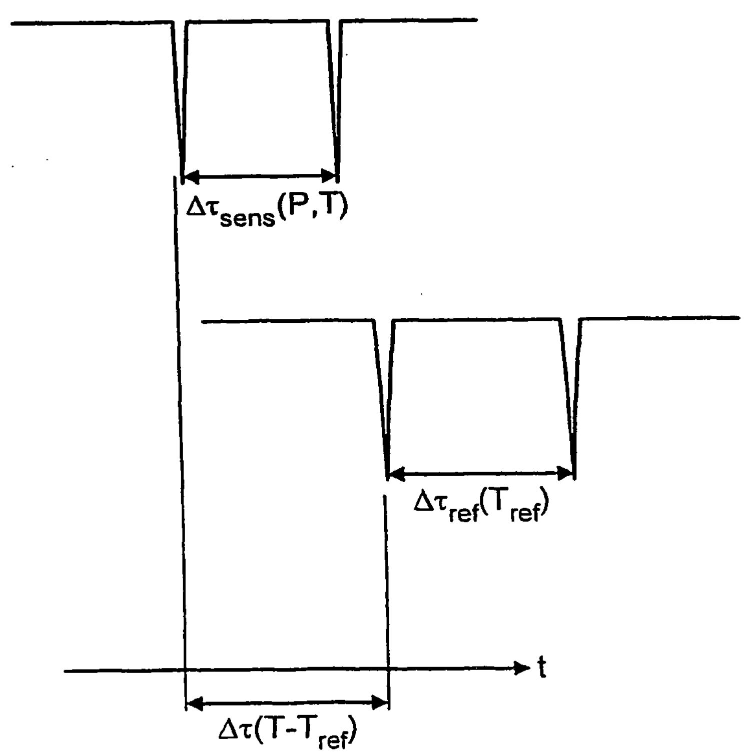
$\Delta\tau_{sens}(P,T)$
$\Delta\tau_{ref}(T_{ref})$
t
$\Delta\tau(T-T_{ref})$

FIG. 4d

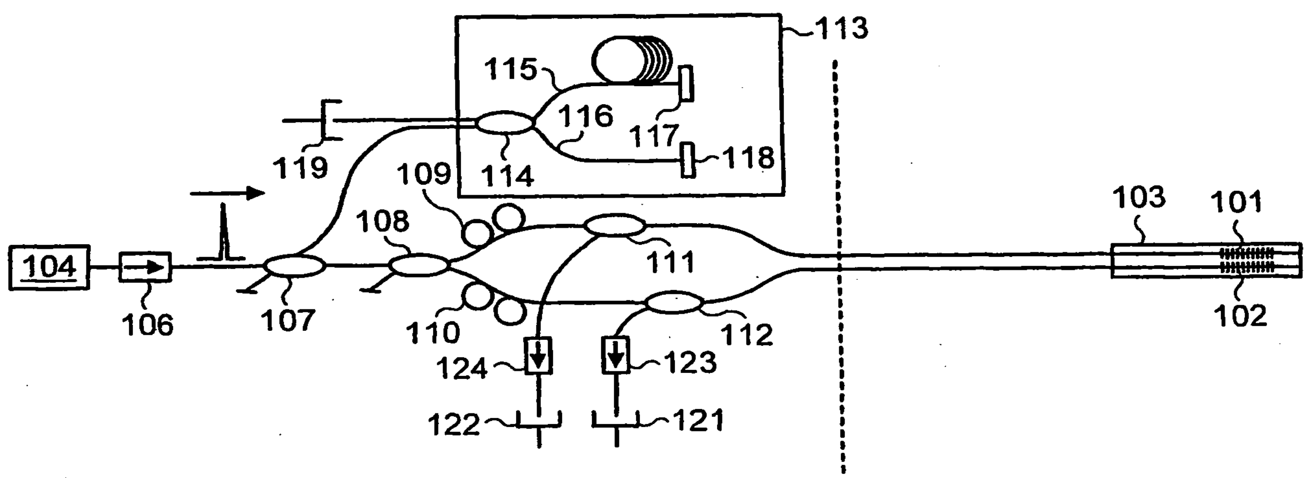
113
115
116
117
118
119
114
109
108
111
103
101
104
106
107
110
112
102
124
123
122
121

FIG. 5

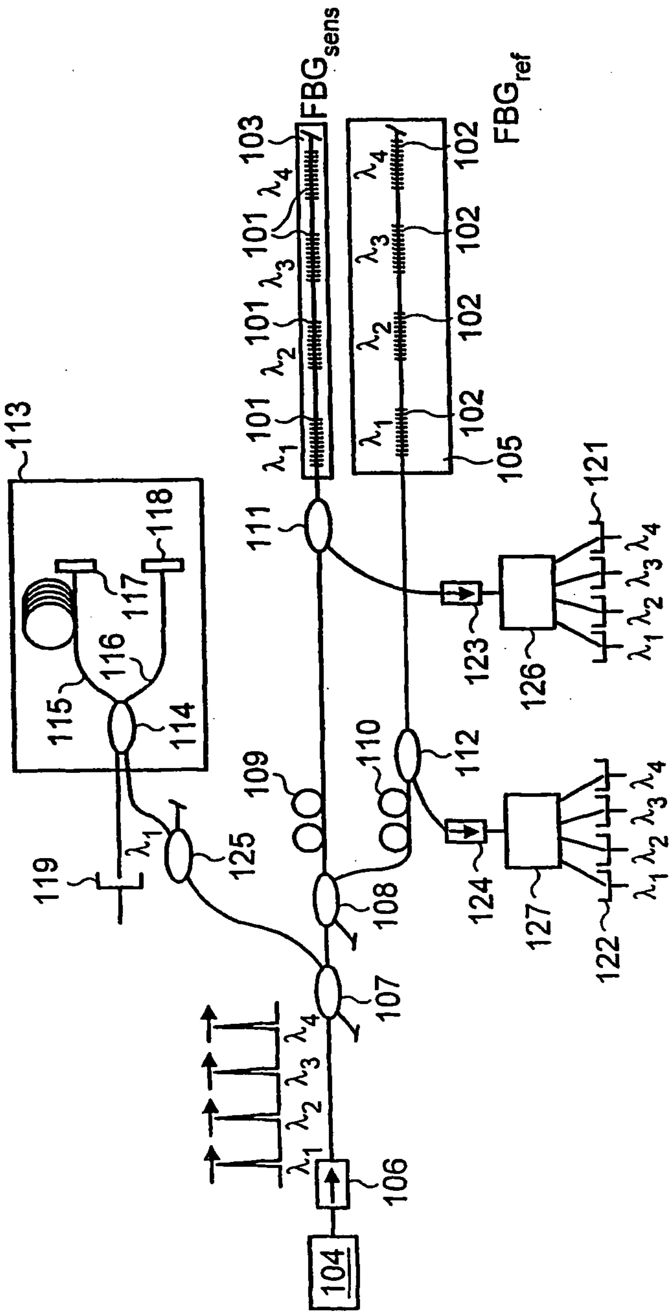
104
106
107
108
109
110
111
112
113
114
115
116
117
118
119
121
122
123
124
125
126
127
101
102
103
105
λ_1 λ_2 λ_3 λ_4
FBG_{sens}
FBG_{ref}

FIG. 6

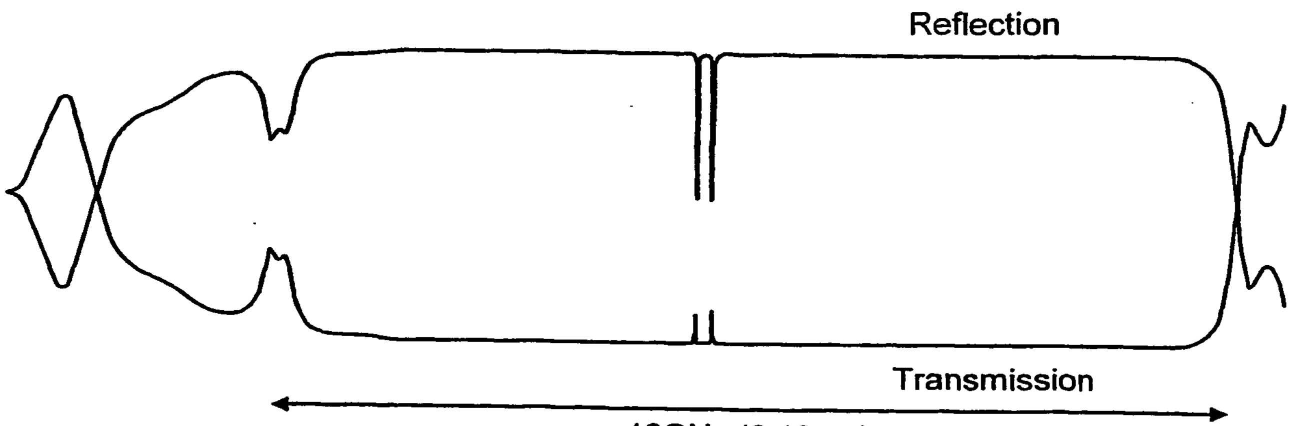

FIG. 7a

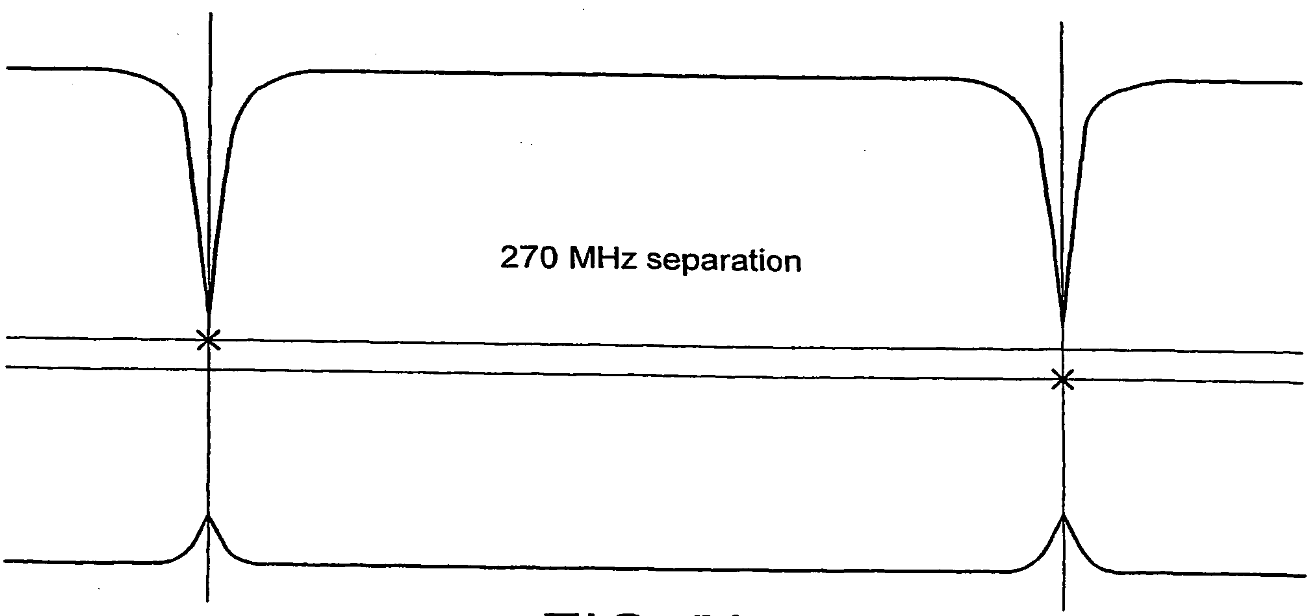

FIG. 7b

INTERNATIONAL SEARCH REPORT

PCT/GB 01/05490

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 G01D5/353 H01S3/067 G01L1/24

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7 G01D H01S G01B G01L

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 6 137 573 A (LLOYD PETER A ET AL) 24 October 2000 (2000-10-24) the whole document ---	1,2
A	US 5 844 927 A (KRINGLEBOTN JON THOMAS) 1 December 1998 (1998-12-01) cited in the application the whole document ---	1,4
A	US 6 097 487 A (NAKSTAD HILDE ET AL) 1 August 2000 (2000-08-01) cited in the application the whole document ---	1
A	US 5 564 832 A (BALL GARY A ET AL) 15 October 1996 (1996-10-15) cited in the application the whole document ---	1,4
	-/--	

[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

° Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
25 February 2002	05/03/2002

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL – 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	Arca, G

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication,where appropriate, of the relevant passages	Relevant to claim No.
A	ZHANG W ET AL: "A fibre grating DFB laser for generation of optical microwave signal" OPTICS AND LASER TECHNOLOGY, ELSEVIER SCIENCE PUBLISHERS BV., AMSTERDAM, NL, vol. 32, no. 5, July 2000 (2000-07), pages 369-371, XP004219832 ISSN: 0030-3992 abstract	1

FURTHER INFORMATION CONTINUED FROM PCT/ISA/ 210

Continuation of Box I.2

Claims Nos.: 13-67

In view of the large number and also the wording of the claims presently on file, which render it difficult, if not impossible, to determine the matter for which protection is sought, the present application fails to comply with the clarity and conciseness requirements of Article 6 PCT (see also Rule 6.1(a) PCT) to such an extent that a meaningful search is impossible. Consequently, the search has been carried out for those parts of the application which do appear to be clear (and concise), namely a two-parameter sensor system comprising two dual-polarisation fibre DFB lasers, as disclosed on page 15 through 17 of the application and in figure 1a and 1b, corresponding to claims 1-12

The applicant's attention is drawn to the fact that claims, or parts of claims, relating to inventions in respect of which no international search report has been established need not be the subject of an international preliminary examination (Rule 66.1(e) PCT). The applicant is advised that the EPO policy when acting as an International Preliminary Examining Authority is normally not to carry out a preliminary examination on matter which has not been searched. This is the case irrespective of whether or not the claims are amended following receipt of the search report or during any Chapter II procedure.

INTERNATIONAL SEARCH REPORT

PCT/GB 01/05490

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